1 Introduction and state of the art

1.1 Introductory words and definition

Following the first trials in the 1970s and more than four decades of R&D work on ballastless track, the level of development is such that it can be confirmed that ballastless track is suitable for use as an alternative to ballasted track. This book is based on the principles of *Eisenmann* and *Leykauf*, which were published in Beton-Kalender 2000, and makes a contribution to the state of the art of ballastless track by describing the basics for designing the slab.

A concrete ballastless track is a non-ballasted form of superstructure in which the loadbase function of the ballast is performed by a layer of concrete. Besides the aim of a longest possible service life and at the same time low maintenance requirements, the superstructure should be founded protected against the effects of frost and supported such that deformations are essentially ruled out.

1.2 Comparison between ballasted track and ballastless track

One of the advantages of a ballastless track compared with ballasted track is that maintenance requirements are minimized. With ballasted track, tamping and lining works at regular intervals are essential. The critical frequency range for increased wear of the ballast forming the track bed begins at about 30 Hz. This excitation frequency is reached at a speed of about 270 km/h with a bogie wheelbase of 2.50 m and an otherwise ideal wheel-rail contact. However, in addition to train speeds, there are other factors that have an influence on the frequency, e.g. wheel defects or defects in the rail running surface. As train speeds increase, so the ensuing frequencies, with increasing amplitudes and higher dynamic loads, result in the need for shorter intervals between ballast maintenance works [1–3].

Another factor affecting loads on the superstructure is the stiffness; as the stiffness of a track system increases, so do the loads on the ballast. In particular, bridges and tunnels, of which there are numerous examples on new and upgraded lines, lead to a higher system stiffness owing to the hard subsoil (bridge superstructure, tunnel invert) and so the loads on the ballast are very pronounced. The long-term behaviour of the ballast can be improved through suitable measures, e.g. the use of sleepers with enlarged bearing surfaces, elastic or highly elastic rail fastening systems, under-sleeper pads or under-ballast mats [3]. Experience shows that with train speeds exceeding 250 km/h, ballasted track already requires maintenance after about 100 million tonnes of load has passed over it. With 100 high-speed trains per day in each direction, that corresponds to a maintenance interval of only a few years. Therefore, Deutsche Bahn AG started specifying ballastless track as the standard form of superstructure for all new lines with train speeds >250 km/h as early as the mid-1990s.

Besides the wear to and redistribution of the ballast during its lifetime, the quality of the position of the track is an important criterion for ballasted track, as the track position steadily worsens over time. The need for tamping and lining work depends

Ballastless Tracks, First Edition. Stephan Freudenstein, Konstantin Geisler, Tristan Mölter,
Michael Mißler and Christian Stolz.

on whether defined guide and limit values for track position parameters have been exceeded. Those guide and limit values should guarantee, primarily, stable wheelset running as well as good ride comfort. In contrast to ballasted track, a ballastless track guarantees that the track remains permanently correctly positioned with a defined track elasticity and eliminates the ballast maintenance measures necessary while ensuring a longer service life. A theoretical service life of 60 years for ballastless track is the aim [4].

The first ballastless track pilot project was carried out at Rheda station in 1972 and so Germany already has more than 40 years of experience with this form of construction. It is therefore clear that a service life of 60 years is certainly practical and, consequently, can be assumed.

Despite the long service life, however, it is necessary to guarantee that individual ballastless track components can be removed and renewed.

It can generally be assumed that the cost of a ballastless track installation on a plain track will be higher than that of the initial installation of a ballasted track with subgrade. However, the maintenance costs of the former lie well those of the latter. It is interesting to note that in tunnels on new lines, ballastless track can be laid more economically than ballasted track with an under-ballast mat.

When considering the economics of ballastless track, it is also necessary to take into account that a ballastless track can be laid with tighter alignment parameters. Better cant deficiency and cants can be achieved with a ballastless track than is the case with ballasted track.

Therefore, for high-speed rail lines, a ballastless track can be built with tighter radii and, if required, steeper gradients for the same design speeds. The outcome of that is a significant economic advantage because savings can be made when building large bridges or tunnels. The savings that can be made during the construction, operation and maintenance of just these complex and expensive engineering structures alone can quickly compensate for the extra cost of ballastless track compared with ballasted track. At the same time, it is possible to route lines alongside motorways and thus keep different modes of transport together.

Another advantage of ballastless track is that it avoids ballast being thrown about – a dangerous phenomenon that is caused by suction forces below a train or ice in winter, which can loosen particles. Loose particles can damage the running surface of the rail or other items in the immediate vicinity. Some countries, e.g. South Korea, are therefore starting to cover whole sections of track with elastomeric sheeting in order to overcome the dangers of flying ballast particles. Furthermore, unrestricted use of eddy current brakes on trains is only possible on ballastless track.

Yet another benefit is the lower construction depth while still maintaining the same cross-section. This is especially interesting for sections of track in tunnels. On the one hand, a smaller tunnel cross-section can be chosen for new lines, which in turn saves costs. On the other hand, on existing lines that, for example, are to be electrified, the installation of ballastless track can avoid having to enlarge a tunnel cross-section in some circumstances. This also means it is easily possible to refurbish old tunnels by installing a new lining.

In recent years there were a number of accidents in tunnels and so new and refurbished tunnels now include vehicular access. Vehicles can drive along a suitably modified ballastless track, so the superstructure can be used by emergency vehicles in order to rescue passengers or recover goods following an incident. As the superstructure is already very stable and firmly positioned, most ballastless track systems can be easily modified to incorporate a flat road surface. Providing access for vehicles across ballasted track is extremely awkward and costly, and it must be remembered that such means of access must be removed to enable the necessary tamping and lining work to be carried out and then reinstalled. Therefore, in future, laying ballasted track in tunnels where access is required for road vehicles as well cannot be justified on economic grounds.

A ballastless track has significant advantages when it comes to the environment as well. In contrast to ballasted track, controlling the growth of plants and weeds by chemical or physical means is unnecessary. That reduces the impact on the environment and, from the economics viewpoint, overcomes the need to apply herbicides and pesticides.

Owing to the reduced maintenance requirements, the distances between transfer points can be increased when building a ballastless track compared with ballasted track – even on busy routes. As that saves on switches and the associated signalling, that is another obvious economic advantage.

For trams and light rail systems in towns and cities, grass can be laid in a ballastless track, which besides the visual and ecological aspects, also improves noise control. In addition, the grass strips can be provided with a permeable base layer to avoid creating an impervious surface. For urban areas in particular, and taking into account the greater incidence of heavy rainfall likely in the future, this is a very significant advantage of ballastless track. When it comes to inter-city rail traffic, the benefits of laying grass between the rails are still being investigated in trials.

Despite all the aforementioned advantages of ballastless track, it should not be forgotten that, on the whole, laying a ballastless track involves a higher capital outlay, and the costs of potential renewal, modernization or modifications are much higher than those of ballasted track. Therefore, it is enormously important that a ballastless track installation be well thought out, properly engineered according to acknowledged codes of practice and always accompanied by scientific studies. In particular, the design of a ballastless track should not be carried out exclusively according to economic criteria. Instead, the design must always be backed up by a certain amount of experience.

1.3 Basic ballastless track types in Germany – the state of the art

There are essentially two types of ballastless track:

- With discrete rail seats,
- With continuous support.

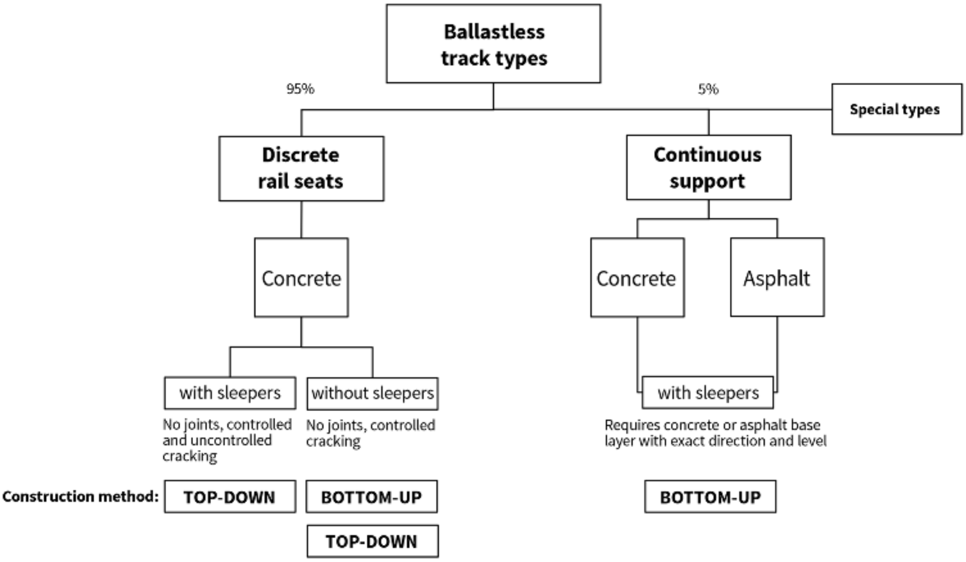


Fig. 1.1 Classification of ballastless track types (source: DB Netz AG)

There are also several special types of ballastless track, such as the continuously embedded rail, which, however, so far have been used almost exclusively for trams and light rail systems in towns and cities.

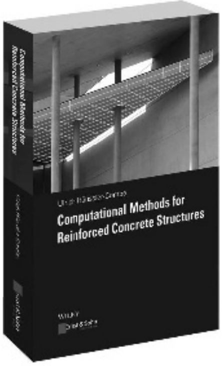
Figure 1.1 shows a detailed breakdown of these two types. We distinguish between discrete forms with or without sleepers and between continuous systems on asphalt or concrete basepavement, both with sleepers.

1.3.1 Developments in Germany

Wheelset loads and train speeds have been increasing constantly since Germany's first railway, the Ludwigsbahn between Fürth and Nuremberg, started operating in 1835. By 1900, speeds had already risen to 100 km/h and axle loads to 14 t. Now, in the twenty first century, the axle loads of freight trains are 22.5 t and passenger trains travel at speeds of 300 km/h, which means that the loads on the superstructure have increased substantially (see Figure 1.2). As increasing axle loads and, in particular, the high speeds lead to ballast having to be lined and tamped at ever shorter intervals [1,2,6], railway authorities had the idea of a non-ballasted superstructure, the ballastless track.

In the meantime, in Germany about 1300 km of ballastless track has already been laid or is currently being installed (approx. 320 km in the VDE 8 rail project as of June 2014). More than 95% of that is of the discrete rail seat type, and only about 5% the continuous support type on asphalt or concrete basepavement (see Figure 1.1).

A test ballastless track was laid at Hirschaid station on the Nuremberg–Bamberg line before 1970. However, it was removed not long after being laid and so relatively little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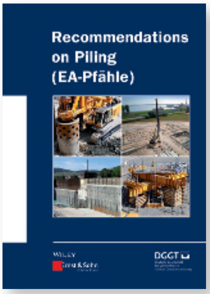

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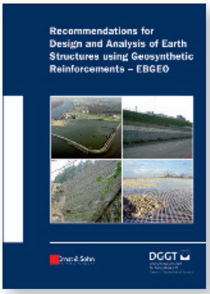

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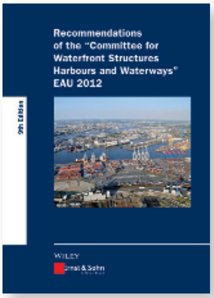

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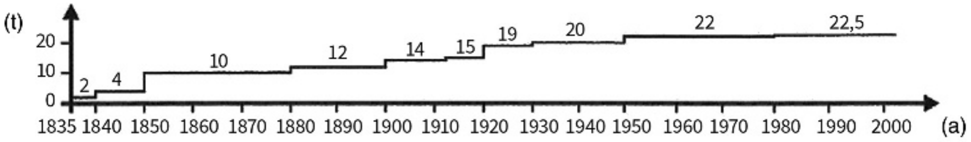
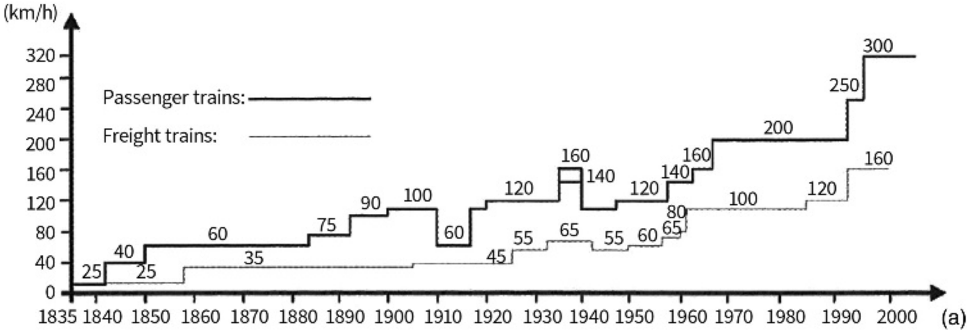


Development of wheelset loads for passenger and freight trains



Development of speed in km/h for passenger and freight trains

Fig. 1.2 Development of axle loads and train speeds over the years (source [5])

useful information is available about this stretch of line. Intensive research into ballastless track began in 1971 and led to the development of the 'Rheda' type, named after the place where it was installed, Rheda/Wiedenbrück station on the Bielefeld–Hamm line, in 1972 (see Figure 1.3). This ballastless track type was designed at the forerunner of today's Institute of Road, Railway and Airfield Construction of Technical University of Munich and research and further development continued after the track was laid [7,8].

Based on that work, various companies started to develop a number of different ballastless track forms that were indeed installed. What that means is that the Federal Railway Authority has in the meantime approved more than 80 different types for use in the German railway network.

1.3.2 Sleeper framework on continuously reinforced slab

A distinction is made here between the version supporting prestressed concrete sleepers and the version with monolithically integrated sleepers.

The original system installed at Rheda station consists of a continuously reinforced concrete slab below a track panel that, following adjustment, is grouted in concrete. Using a preassembled track panel ensures good quality of rail alignment (gauge, level, etc.), which is very important for high-speed travel in terms of ride comfort and safety. To ensure a bond between the concrete sleepers of the track panel and the slab, holes were provided in the sleepers for reinforcing bars in the longitudinal direction. Stirrups were placed in the slab and encased in the concrete infill (see Figure 1.4).

Fig. 1.3 The Rheda system at Rheda station in 2010 (source: Institute of Road, Railway and Airfield Construction, Technical University of Munich)

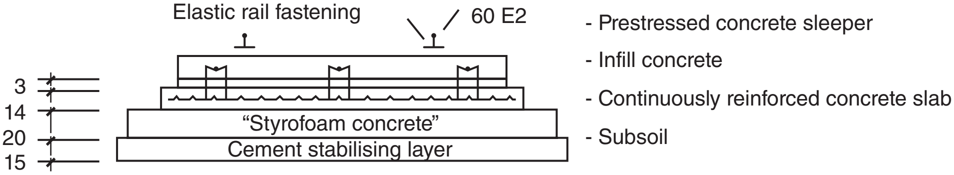


Fig. 1.4 Rheda 1972 superstructure (source: Institute of Road, Railway and Airfield Construction, Technical University of Munich)

The ballastless track at Rheda and those forms based on it were accompanied by the development of highly elastic rail fastening systems, initially by Vossloh, e.g. System 300 (Figure 1.5) or 336, in order to achieve an even, elastic deflection under the wheelset loads despite the stiff concrete superstructure.

This intended deflection of, on average, 1.5 mm under a 20 t axle load reduces the dynamic loading on the superstructure and also improves the load distribution over the slab.

Underneath the slab there is normally either a base layer with a hydraulic binder (BLHB) 30 cm deep or, occasionally, an bituminous base layer. Generally, the superstructure for a ballastless track should be founded frost-resisting below the

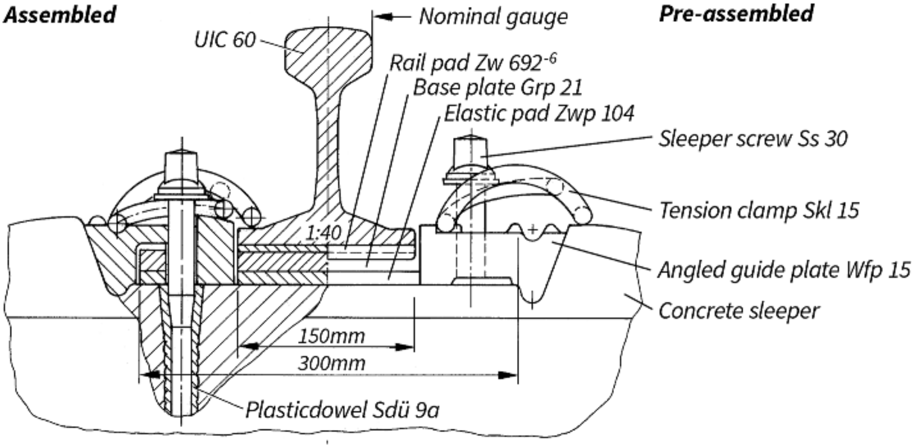


Fig. 1.5 Highly elastic rail fastening system 300, original version

frost penetration depth. Therefore, below the bonded base layers there should be a non-bonded frost protection layer on the prepared subgrade of the *in situ* or filled subsoil. The first superstructure systems with exclusively non-bonded base layers below the slab are still at the planning phase.

Taking the types described above as a starting point, many other ballastless track systems were investigated and designed at national and international level.

1.3.3 Continuously reinforced slab with discrete rail seats

Several ballastless track systems were installed for test purposes at Waghäusel on the Karlsruhe–Mannheim line in 1996. Five of the types installed had the rail seats placed directly on the continuously reinforced slab.

Besides systems for high-speed trains, a version with grass between the rails (see Figure 1.6) was also installed which underwent further development at the predecessor of today's Institute of Road, Railway and Airfield Construction at Technical University of Munich. The design consists of a permeable base layer of concrete with continuously reinforced longitudinal concrete beams above that. However, this system has not proved suitable for inter-city routes.

1.3.4 Precast concrete slabs

Among the few ballastless track systems that have become established in Germany, and also internationally, are those employing precast concrete slabs.

Here, the track panel, and possibly the concrete base layer (see Section 1.3.2), are replaced by precast concrete slabs). In the Bögl system (see Figure 1.7) these precast concrete slabs are prestressed in the lateral direction to limit the width of cracks. In the longitudinal direction, the precast concrete slabs of this system are joined by

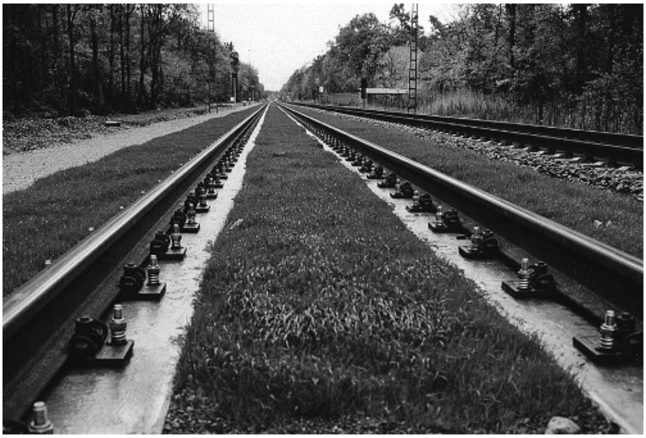


Fig. 1.6 Ballastless track with intermediate grass strip at Waghäusel near Karlsruhe (source: Institute of Road, Railway & Airfield Construction, Munich TU)

Fig. 1.7 Bögl ballastless track system (source: Institute of Road, Railway & Airfield Construction, Munich TU)

turnbuckles on the reinforcing bars. In addition, the aim is to control cracking by notched predetermined breaking points every 0.65 m between the rail seats. The slab is cast following final alignment of the rails (top-down method) using a grout and joined to the hydraulic bonded layer (or other base layer) such that it remains in position. The aim of this grout infill is to ensure the track remains in the right position and also to optimize the bond between the layers (hydraulic bonded layer – slab).

In order to avoid polygon line-type errors in the track positioning, the alignment elements (curves and, in particular, transition curves) must either be included in the